ABSTRACT

A consolidated operations center for Space Shuttle missions has been proposed in the southwestern area of the United States. It is intended to recover both the Booster and Orbiter stages of the Shuttle at this center. The two stages will have aerodynamic flight characteristics similar to conventional large aircraft, and will land on a runway at a suitably equipped airfield.

Two southwestern locations, Edwards Air Force Base, Calif., and Holloman Air Force Base, N. M., are selected for more detailed study, and compared against a center located at Cape Kennedy. The southwestern locations have better flying weather and would permit payload gains due to their higher elevations. However, the Cape Kennedy location would be superior for recovery of single revolution missions or one-revolution aborts.
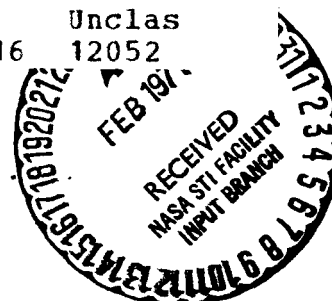
Both stages will carry communications and navigation aid equipment compatible with the Federal Aviation Agency's Air Traffic Control System. Specialized equipment may be carried to permit all-weather landings. Landings will be possible on runways of at least 10,000 ft. length possessing bearing strengths sufficient to support a Booster landing weight of about 500,000 lbs. Ground-based facilities costs for recovery operations will be relatively small, since existing equipment will be used, and hopefully an existing airfield can also be used.

MEMORANDUM FOR FILE

I. INTRODUCTION

This memorandum discusses operational and equipment requirements for recovering Space Shuttle missions in the southwestern U. S. For purposes of this study, this area is arbitrarily taken to be bounded by 40° North latitude and 103° West longitude (Fig. 1). A southwestern location is being considered for a Centralized Operations Center (COC) for launch, flight and mission control, and landing operations for all Shuttle missions. Such a COC would be in lieu of the distributed launch, mission control, recovery, and communications center locations existing at present for manned space flight operations.

The recovery phase for the Booster is assumed to begin at separation from the Orbiter, and extend until termination of landing roll. The recovery phase for the Orbiter is assumed to begin at inbound penetration of 400,000 ft. altitude for a nominal mission, or at separation for an aborted launch mission, and extend until termination of landing roll. In addition, if either vehicle lands at other than the airport associated with the COC, ferry flights to return the vehicle(s) back to the COC are considered to be part of recovery operations. "Safing" of the vehicles following landing and logistics to support ferry flights are not considered a part of recovery operations; safing is discussed in Ref. 1. Recovery opportunities, land areas overflown and the need for alternate landing fields are heavily influenced (chiefly for the Orbiter) by the characteristics of the orbit to be achieved, the payload orbited, and the on-board fuel available. Hence, consideration is given in this memorandum to such non-recovery phase characteristics.

II. SPACE SHUTTLE MODEL

The Space Shuttle model assumed for this study is described more fully in Ref. 2. This section will focus on those characteristics most pertinent to recovery.

The vehicles are those proposed by a contractor team headed by North American Rockwell (NAR), using a straight-wing Booster and either a "long cross-range" delta-wing Orbiter or a "short cross-range" straight-wing Orbiter. (Ref. 3). The long cross-range is 1500 nm, opposed to the short cross-range of 200 nm. The long cross-range version would be needed to return to the COC following single revolution operational missions or those requiring a first revolution abort. The proposed Booster and Orbiters are illustrated in Figs. 2 and 3. At present, the 1500 nm Orbiter appears more likely.

The more significant characteristics of the Shuttle mission model pertinent to recovery operations are:

- A maximum Orbiter aerodynamic cross-range (out-of-plane) capability of either 200 or 1500 nm. This will not require propulsive maneuvering.

- An approximately 6000nm (long cross-range) or 3000 nm (short cross-range) Orbiter down-range distance from reentry at penetration of 400,000 ft. altitude to touchdown; unlike Apollo, not permitting significant down-range variation.

- An Orbiter on-orbit ΔV fuel budget of 1500 fps, restricting phasing burns and other propulsive maneuvers.

- Conventional large aircraft flight characteristics when operating in the subsonic flight regime.

- Avionics compatible with the existing FAA Air Traffic Control (ATC) system.

- Either Category II (poor weather) or "zero-zero" (all-weather) landing capability at the COC and some alternate landing fields.

- A Booster capable of unmanned operation, an Orbiter capable of one-man operation. Both will normally carry a crew of two.

III. RECOVERY REQUIREMENTS AND GUIDELINES

"Requirements" and "desired characteristics" pertinent to recovery of the two Space Shuttle stages are itemized in Table 1. These have been drawn from the Shuttle work statement (Ref. 4). The baseline requirements are considered firm, the desired characteristics should be taken as firm unless convincing reasons

can be developed against them. For the purposes of this study
they will be assumed to be valid requirements. The Category II
landing minimums stated as a desired characteristic require
visibility of at least 100 ft. in altitude and 1200 ft. down
the runway (runway visual range, or RVR). This requires both
suitable airport instrument landing system (ILS) facilities and
on-board equipment. There is considerable support in the
Shuttle program for imposing a Category IIIC, or "zero-zero"
all-weather landing capability requirement on both Shuttle stages.
A consistently reliable operational Category IIIC capability has
yet to be achieved (Refs. 5 and 6), but in view of the support
for it, it is also considered in this study. "Safing" following
landing refers to the removal of any potentially hazardous on-
board conditions due primarily to fuel residuals that may be
left in the rocket or air-breathing engine tanks.

To as great an extent as feasible, the two Shuttle
stages are intended to operate autonomously, with minimal inter-
face with ground facilities. Guidance and navigation through
reentry will be performed primarily using on-board inertial
systems. The FAA-ATC system will monitor the Shuttle, but is
not expected to control it (except perhaps on ferry flights).
Normal FAA-ATC ground-based navigation aids will be used for
cruise and landing. Category IIIC landings would require special-
ized ground equipment at the landing site. This is discussed in
section VI and the Appendix.

IV.   DESCRIPTION OF RECOVERY OPERATIONS

This section describes the assumed orbital/aeronautical se-
quence of events associated with a nominal recovery as visualized by
NAR in Ref. 3. The interface with the ground is not discussed in
this section, as it was not developed by NAR in the quoted reference.
(Our suggested ground operations interface is discussed in Section VI).
In addition, a restricted description of abort operations is included.

The flight profile for a nominal mission is discussed in
Ref. 2. Staging of the Orbiter will occur at about 240,000 ft.
altitude and a velocity of about 11,000 fps. The Booster will
enter with a 60° angle-of-attack. The angle-of-attack will gradually
be lowered as speed is decreased. The air-breathing engines will
be started after entering the subsonic flight regime. Maximum
down-range distance achieved will be about 400 nm. Cruise-back
will be at 20,000 ft. at an air speed of 340 kts. Landing will
occur at about 170 kts. with a rollout distance of about 7000 ft.
(standard sea-level conditions), at a weight of 480,000 lbs.

The long cross-range Orbiter will nominally enter at
400,000 ft. altitude with a flight path angle of -1.55°, a velocity

of about 25,000 fps, and an angle-of-attack of 53° (see Fig. 4).
A pull-up maneuver will be initiated about 1000 nm down-range
from entry, accompanied by a bank maneuver to achieve the
desired cross-range. Transition to a low angle-of-attack will
start about 4000 nm down-range. Subsonic velocity will be
reached about 50 minutes after entry, about 6000 nm down-range.
This will occur approximately over the landing site to minimize
fuel requirements for the air-breathing jet engines. The landing
speed will be about 160 kts, runway roll about 6000 ft., and
the weight about 210,000 lbs.

The short cross-range Orbiter entry profile will be
generally similar (Fig. 4). The initial angle-of-attack will
be somewhat higher (60°) the entry-to-touchdown distance less
(3000 nm), and the time-to-touchdown shorter (about 37 min). The
landing speed would be slightly higher (167 kts).

If an abort is required due to Booster failure, the
Orbiter will make a premature separation and both Booster and
Orbiter will return to the COC. This will be required only if
three or more of the Booster's 12 main launch propulsion engines
fail. A more-or-less nominal orbital mission can still be
accomplished with loss of two Booster engines. It will be
essential for the Booster to dump its main engine propellants,
as it would otherwise be too heavy to land on a runway. The
Orbiter could reach a down-range distance of as much as 600 nm
before turning back.

If Booster flight is normal, but an Orbiter main
engine failure after staging requires an abort, the type of
abort will depend upon the time of failure. During the first
approximately three minutes of Orbiter powered flight, failure
of one of its two main engines would prevent the Orbiter from
reaching orbit. An immediate return to the COC or an alternate
field would have to be made. After this time, an abort to a
100 nm circular orbit could be achieved by using the remaining
main engine and the two orbital maneuvering engines while main-
taining sufficient fuel for a deorbit burn at a favorable time.

The nominal injection orbit of the Orbiter will be 50 x 100
nm. A burn using the orbital maneuvering engines would occur at the
first apogee to make a Hohmann (minimum energy) transfer to the
desired mission orbit. If this burn for any reason cannot be
made, another abort situation will arise due to the low perigee
altitude of the injection orbit. An early return must be made,
since atmospheric drag will be appreciable and the orbit will soon
decay. In such a case, a return near the end of the first revo-
lution using aerodynamic steering will be highly desirable, or
possibly mandatory.

For both vehicles, a normal aerodynamic cruise and landing could be made with loss of one of the four air-breathing engines. Loss of the complete air-breathing system in the Booster would still make possible an unpowered landing at a downrange location. Loss of the complete air-breathing system for the Orbiter would permit landing at the COC in an unpowered mode provided the reentry were properly targeted and executed. There would obviously be no go-around capability in either case.

V.   OPERATIONAL CONSTRAINTS

A long cross-range Orbiter considerably eases recovery constraints relative to a short cross-range Orbiter. The requirement for a capability to return from Space Station orbit at least once every 24 hrs. necessitates either a cross-range capability of up to about 500 nm or the use of a phasing orbit first (and a slight fuel penalty).

Existing airfields in the southwest (bounded by 40° N latitude and 103° W longitude) with runway lengths of at least 10,000 ft. are listed in Table 2. There are as of today 40 fields in this category, 15 commercial and 25 military. Five commercial and ten military fields may not possess sufficient runway bearing strength to permit Booster landings, though all should be adequate for the Orbiter. Since it is desired to have a common facility, 10 commercial and 15 military fields currently qualify. The 10,000 ft. runway criterion presumably is for mean sea level standard wind and temperature conditions. No attempt was made to adjust for these conditions. All other things being equal, a higher elevation or a higher temperature will require a longer runway length for the same landing weight. Two southeast sites, Edwards AFB, Calif., and Holloman AFB. N.M., have been selected as having potentially desirable locations and existing facilities for establishment of a COC. Edwards has a 15,000 ft. heavy duty runway, plus a dry lake run-out extension to 35,000 ft. It is at 2300 ft. elevation. Holloman has a 12,000 ft. heavy-duty runway, and is at an elevation of 4100 ft. Each foot of elevation is roughly equivalent to one extra pound of payload for a fixed lift-off weight. The relative advantages and disadvantages of these two sites vs. Cape Kennedy are discussed in Ref. 9. No suitable airfield currently exists in the Cape area, although two commercial and three military fields on the Florida peninsula would be adequate (Table 3).

Of special significance to recovery is the landing visibility at these sites. FAA landing minimums in terms of ceiling and visibility are defined as follows:

Category	Minimum Ceiling(ft)	Minimum RVR(ft)
I	200	2400
II	100	1200
IIIA	50	700
IIIB	0	150
IIIC	0	0

The most liberal interpretation of shuttle landing requirements is for Category II capability; however, a Category IIIC capability was established as desirable for the purpose of this study. Ceiling and visibility data for the three candidate sites, from Ref. 10, is summarized in Table 4. All three sites have generally good visibility, with Edwards, Holloman, and the Cape rated in descending order. The granularity of the source data does not permit determination of how often Category IIIA, B, and C conditions could be expected to occur, but the trend appears clear.

Determination of the ceiling is a crew responsibility. They must satisfy themselves that they have solid ground visibility before reaching the altitude minimum. Runway visual range information is obtained by a "transmissometer" on the ground, and radioed to the crew. Go-around capability for both Shuttle stages is expected to be restricted to once due to fuel limitations.* Orbiter landing visibility will be a greater unknown than Booster landing visibility. For all but very rare emergency rescue missions, launches can be held for adverse weather conditions, so that a Booster landing at the COC about two hours later can be almost assured to be made under favorable conditions. The Orbiter landing, in contrast, could be as much as a week after launch (Shuttle resupply mission), or a month after launch (independent Shuttle mission). The Orbiter will be able to redesignate a landing site while in orbit should bad weather develop at the COC. If the COC has a fully operational, redundant, Category IIIC capability, a landing there is by definition always possible. Otherwise, an alternate field must be selected prior to deorbiting. The air-breathing engine fuel to be carried for Orbiter subsonic cruise, approach, and landing will permit a maximum of about 15 minutes operation.

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*Consideration is being given to eliminating the air-breathing engines on the Orbiter and possibly on the Booster. It is believed the Orbiter reentry can be controlled precisely enough that non-propulsive aerodynamic maneuvering will be sufficient to reach the COC and permit a safe, controlled landing. Similarly, sufficient aerodynamic control could be maintained over the Booster to permit it to make a downrange landing. No-go around capability would be available, and for the Booster strap-on engines and fuel tanks would be needed for ferry flight back to the COC.

Current thinking by the Shuttle study contractors and NASA is that it is desirable to have both vehicles make a very steep landing approach (a glide slope on the order of 10° vs the more conventional 2.5° to 3°) and land at a relatively high speed. No power would be used; the air-breathing engines would be operating at idle to permit a missed approach pull-up. If such a mode of operation were used, a higher go-no go decision height will be required, and the landing category requirements would need to be redefined.

Since there will be sonic booms generated by both vehicles, it is desirable to have the COC located away from major population centers. Also, the launch and return ground tracks should not fall over heavily populated regions when operating at relatively low altitudes within the atmosphere. From this viewpoint, East coast launches and West coast recoveries would be optimum. None of the three candidate COC sites has a clear-cut advantage in this respect. The problem is expected to be minor, at least when compared against supersonic transport operations, because of the limited atmospheric flight path length (mostly at high altitudes) and the relative infrequency of Shuttle flights (Ref. 11).

A southwest COC location is less desirable than the Cape for recovery following single revolution operational missions or first revolution aborts. This is particularly significant if the short cross-range Orbiter should be selected. Figures 5-10 show the ground tracks for the first revolution of the design reference 50 x 100 nm 55° inclination insertion orbit (for Space Station resupply) for each of the three candidate sites. These figures assume no atmospheric effects. Since 50 nm is below the generally accepted reentry altitude of 400,000 ft. where atmospheric effects begin to be significant, a second revolution might not be possible, or might result in a significantly perturbed orbit.

If a short cross-range Orbiter vehicle is used for the Shuttle, it is clearly impossible to return to the COC after one revolution. The Earth's rotation will cause the longitudinal spacing between successive crossings of the same latitude to be about 1100 nm in the latitude band of interest. Thus, about 1000 nm cross-range capability will be required to return to the COC. A short cross-range Orbiter would have to select an alternate landing site for a one revolution mission. Figs. 5-7 show the alternate field possibilities for a launch with a northeast heading. A launch from Edwards would only have the extreme northwest U. S. available for a short cross-range recovery. From Holloman, a larger area starting at about San Francisco would be

available. From the Cape, a wide range of the central U. S. from Texas to Michigan would be available. Figs. 8-10 show the corresponding ground tracks for a launch with a southeast heading. The southeast launch heading is generally believed to be less desirable since it would require overflying Mexico or Cuba during the launch phase ascent.

Figs. 5-10 were derived to illustrate first revolution abort options assuming a short-cross range Orbiter. They are also applicable to single revolution operational missions. However, these missions could be at other inclinations than the 55° inclination used for Space Station resupply. Also, assuming normal on-orbit propulsion to be available, burns can be made to alter the reentry point and flight path angle, or to make a plane change. Consequently, much more flexibility exists for return from these missions than from an aborted one.

VI.   PROPOSED RECOVERY SYSTEM

Recovery of the two Shuttle stages will be quite rigidly constrained. The Booster will fly about 400 nm downrange, reach about 240,000 ft. altitude and fly back to the COC at subsonic speed using its air-breathing engines. The Orbiter will reenter either 3000 or 6000 nm downrange, slowdown to subsonic speed almost directly above the COC, and use its air-breathing engines only very briefly while making the landing. Both stages will have sufficient fuel to execute one missed approach go-around.

The recovery air-ground interface for nominal operations is visualized as summarized below. Details on communication and navigational aid equipment and operation are given in the Appendix.

Booster. Voice communications with the Booster will be maintained via VHF/UHF transceivers. No real-time telemetry or command capability will be required. The Booster will not be traveling at a velocity high enough for communications blackout to occur. On-board inertial navigation equipment will be prime, but the capability to use conventional ground-based VHF Omnidirectional Range/Distance Measuring Equipment (VOR/DME) and military Tactical Air Navigation (TACAN) equipment will be provided. An Air Traffic Control Radar Beacon System (ATCRBS) transponder will be carried to aid the ground in positive vehicle identification and establishment of altitude.

It appears feasible to obtain from the FAA an advance reservation to clear a block of airspace for Shuttle operations. ATC would monitor the Shuttle flight path, but not attempt to control it. Other aircraft would be excluded from this block

during the time period reserved. The desirability of doing this stems from the limited on-board fuel supply, the limited land area overflown, and the relative infrequency of Shuttle flights. Informal discussions with FAA personnel indicate they would be receptive to doing this, provided reasonable advance notice is given.

Separate ground-based communications and tracking equipment for the cruise-back portion of the Shuttle flight does not appear to be warranted. Voice communications and tracking data could be remoted from the FAA facilities to the COC, if needed. Alternatively, COC personnel could be stationed at FAA traffic control centers, and be provided with communications to the COC.

Ground-based facilities will be required for the Shuttle at the landing field. If an existing field is used, most or all of these facilities except those needed for Category IIIC operation will already be in existence. These facilities, described in the Appendix are:

(1)   VHF/UHF voice communication equipment

(2)   Airport Surveillance Radar (ASR)

(3)   Secondary Surveillance Radar (SSR), the ground-based portion of the ATCRBS

(4)   Category II Instrument Landing System (ILS)

(5)   Microwave ILS

(6)   Ground Control Approach (GCA) or Precision Approach Radar (PAR)

(7)   Medium Intensity Approach Light System (MALS) with Runway Alignment Indicator Lights (RAIL)

(8)   Airport Surface Detection Equipment (ASDE)

(9)   Transmissometer, to measure Runway Visual Range (RVR)

(10) Up-data link (for possible unmanned Booster operation)

(11) Control tower or control room

(12) Category IIIC equipment, if the microwave ILS is not adequate.

Implementation of a Category IIIC landing capability is presently uncertain. The microwave ILS, to be operational around 1975, will permit more accurate approaches to lower altitudes than the present ILS, but probably not good enough for Category IIIC. For automatic operation, it is possible to think in terms of a precision radar altimeter on-board, plus ground-based transponders for determination of runway location and alignment. Information from these sources would be fed to the Booster autopilot to control the final approach, flare, decrab, touchdown, and roll-out operations. The up-data link would permit the ground to back-up the on-board system.

Orbiter. Voice communications with the Orbiter would be maintained via communication relay satellite until reentry. During reentry, vehicle attitude constraints and/or plasma sheath effects may make communications unreliable or impossible. After the plasma effects have subsided, voice communications would be established with the ground via the VHF/UHF system as for the Booster. Since the slowdown to subsonic flight is to be targeted for very near the landing field, it is probable that the COC would be in direct communications with the Orbiter during the time it was in FAA-controlled airspace (see Fig. 4).

As with the Booster, a block of airspace would be reserved with the FAA, and the FAA would monitor the entry to the extent their facilities permitted. The size of this block would have to be sufficient to allow for dispersions caused by reentry maneuvers.

The same on-board and ground equipment would be provided for the Orbiter as for the Booster. Category IIIC landing capability would also be provided, although an unmanned operating mode would not be required.

If the Booster or Orbiter were required to land at other than the prime site, some of the ground-based equipment listed above may not be available. Most of the airfields listed in Table 2 and 3 (and most others of comparable size around the world) will be equipped for Category II landings by 1980, but very few, if any, will be equipped for Category IIIC.

VII. CONCLUSIONS

A southwestern location for the Space Shuttle COC is feasible from a recovery viewpoint. An optimum location would be at an existing well equipped airfield, preferably military, not near any large population centers, and situated so that the most frequently used launch and return azimuths would not overfly

heavily populated areas. A southwestern COC would not be as
desirable as a COC at Cape Kennedy for recovery of a short
cross-range Orbiter. Recovery flight operations could be
conducted using existing FAA air traffic control facilities.
Specialized equipment at the COC would be needed if all-weather
landings are a requirement.

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Appendix
Attachments
   Tables 1-4
   Figs. 1-10

TABLE 1

(FROM REF. 4)

"BASELINE" REQUIREMENTS

VEHICLE

O - 200 NM OR 1500 NM MAXIMUM AERODYNAMIC CROSS-RANGE CAPABILITY

B,O - INTACT ABORT CAPABILITY

B,O - FERRY FLIGHT CAPABILITY

B,O - "GO-AROUND" CAPABILITY IN EVENT OF MISSED LANDING APPROACH

B - RETURN TO LAUNCH SITE CAPABILITY AS PART OF NOMINAL MISSION

DESIRED CHARACTERISTICS

B - CAPABILITY FOR UNMANNED OPERATION

O - CAPABILITY FOR ONE-MAN OPERATION

B,O - AUTOMATIC LANDING APPROACH CAPABILITY - CATEGORY II

B,O - ON-BOARD "SAFING" FOLLOWING LANDING

O - RETURN TO LAUNCH SITE CAPABILITY AT LEAST ONCE EVERY 24-HOURS

B,O - CAPABILITY OF LANDING AT OTHER SELECTED SITES IN CONTINGENCY MODE

B,O - CAPABILITY OF LANDING ON 10,000 FT. RUNWAYS

B - BOOSTER

O - ORBITER

Table 2

(From Ref. 7 & 8)

Airports In S. W. U. S. Having 10,000 Ft. Runways
(Bounded by 40°N Latitude, 103°W Longitude)

Airport	Lat.(N)	Long.(W)	Elev. (ft.)	Longest Runway(ft)	Twin-Tandem Load Capacity[1] (lbs)	
California						
Beale AFB	39°08'	121°26'	113	12,000	490,000	
Castle AFB	37°23'	120°34'	188	11,800	415,000	
China Lake NAF	35°41'	117°41'	2288	10,000	201,000	(2)
Edwards AFB	34°54'	117°52'	2302	15,000	560,000	
El Toro MCAS	33°40'	117°44'	383	10,000	275,000	(2)
George AFB	34°35'	117°23'	2875	10,000	440,000	
Lemoore NAS	36°20'	119°57'	237	13,500	385,000	
Los Angeles (Int'l.)	33°56'	118°24'	126	12,000	340,000	
Long Beach (Int'l.)	33°49'	118°09'	58	10,000	180,000	(2)
March AFB	33°54'	117°15'	1868	10,100	290,000	(2)
Mather AFB	38°34'	121°18'	96	11,300	445,000	
McClellan AFB	38°40'	121°24'	76	10,600	500,000	
Miramar NAS	32°52'	117°09'	477	10,000	308,000	(2)
Norton AFB	34°06'	117°14'	1156	10,000	390,000	
Oakland (Metro. Int'l.)	37°43'	122°13'	6	10,000	400,000	
Ontario (Int'l.)	34°03'	117°36'	952	10,000	220,000	(2)
Palmdale AF	34°38'	118°06'	2549	12,000	530,000	
Pt Mugu NAS	34°07'	119°07'	13	11,100	364,000	
San Francisco (Int'l.)	37°37'	122°23'	10	10,600	400,000	
Travis AFB	38°16'	121°56'	62	11,000	470,000	
Nevada						
Fallon NAAS	39°25'	118°42'	3934	14,000	177,000	(2)
Las Vegas (McCarran Int'l.)	36°05'	115°09'	2171	12,500	172,000	(2)
Nellis AFB	36°15'	115°02'	1868	10,100	290,000	(2)
Arizona						
Davis-Monthan AFB	32°10'	110°53'	2705	13,600	345,000	
Luke AFB	33°33'	112°22'	1101	10,000	195,000	(2)
Phoenix (Sky Harbor)	33°26'	112°01'	1128	10,300	350,000	
Tucson (Int'l.)	32°07'	110°57'	2630	12,000	360,000	
Williams AFB	33°18'	111°40'	1385	10,400	120,000	(2)
Yuma (Int'l.)	32°39'	114°37'	213	13,300	410,000	
New Mexico						
Albuquerque-Kirtland AFB	35°03'	106°36'	5352	12,700	400,000	
Cannon AFB	34°23'	103°19'	4295	10,000	240,000	(2)
Holloman AFB	32°51'	106°06'	4094	12,200	380,000	
Roswell (Indust. Air Center)	33°18'	104°32'	3669	13,000	480,000	
Utah						
Michael AAF (Dugway Proving Ground)	40°11'	112°56'	4349	13,100	?	(2)

Table 2 (Cont.)

Airport	Lat.(N)	Long.(W)	Elev. (ft.)	Longest Runway(ft)	Twin-Tandem Load Capacity[1] (lbs)
Colorado					
Buckley ANGB	39°42'	104°45'	5663	11,000	280,000
Colorado Springs (Peterson)	38°49'	104°43'	6172	11,000	340,000
Denver (Stapleton)	39°46'	104°53'	5330	11,500	350,000
Pueblo (Mem.)	38°17'	104°30'	4725	10,500	230,000 (2)
Texas					
Biggs AAF	31°51'	106°23'	3947	13,600	440,000
El Paso (Int'l.)	31°48'	106°23'	3956	12,000	280,000 (2)

[1]Maximum load capacity for aircraft with twin-tandem gear. Booster gear probably will permit landing at fields twin-tandem rated at 310,000 lbs. or higher.

[2]Airports that might not have sufficient runway bearing strength for landing Booster. Orbiter is probably capable of landing at any of above fields.

Table 3

(From Ref. 7 & 8)

Major Airports on Florida Peninsula

Name	Lat(N)	Long(W)	Longest Runway(ft)	Twin-Tandem Load Capacity (lbs)
Cape Kennedy Regional (Melbourne)	28°06'	80°38'	9,500	350,000
Dade-Collier Training & Transition (Everglades)	25°52'	80°54'	10,500	400,000
Homestead AFB (Homestead)	25°29'	80°24'	11,200	545,000
MacDill AFB (Tampa)	27°51'	82°31'	11,400	380,000
McCoy AFB (Orlando)	28°26'	81°19'	12,000	540,000
Miami International	25°48'	80°17'	10,500	350,000
Patrick AFB	28°14'	80°36'	9,000	325,000

Table 4

Landing Visibility to be Expected at Candidate COC Sites
Percent of Time Weather Can be Expected to be Below FAA Category Minimums[1,2]

Site	Edwards AFB		Holloman AFB		Cape Kennedy	
Category	I	II	I	II	I	II
Month						
Jan.	.3%	.3	.3%	.2	1.0%	.6
Feb.	.1	.0	.2	.1	.5	.3
Mar.	.2	.1	.2	.1	.4	.2
Apr.	.1	.1	.4	.2	.2	.1
May	.1	.0	.2	.1	.1	.0
June	.0	.0	.1	.1	.1	.0
July	.0	.0	.1	.1	.0	.0
Aug.	.0	.0	.0	.0	.1	.0
Sept.	.0	.0	.0	.0	.1	.0
Oct.	.1	.0	.0	.0	.2	.1
Nov.	.1	.0	.1	.1	.1	.1
Dec.	.3	.3	.6	.5	.9	.6
Over-All Avg[3]	.11	.07	.18	.13	.31	.17

[1] Category I minimums: ceiling 200 ft, visibility 2400 ft. RVR
  Category II minimums: ceiling 100 ft, visibility 1200 ft RVR

[2] Data based upon 202,350 samples all months from Edwards, 195,068
  samples all months from Holloman, 129,998 samples all months from Cape.

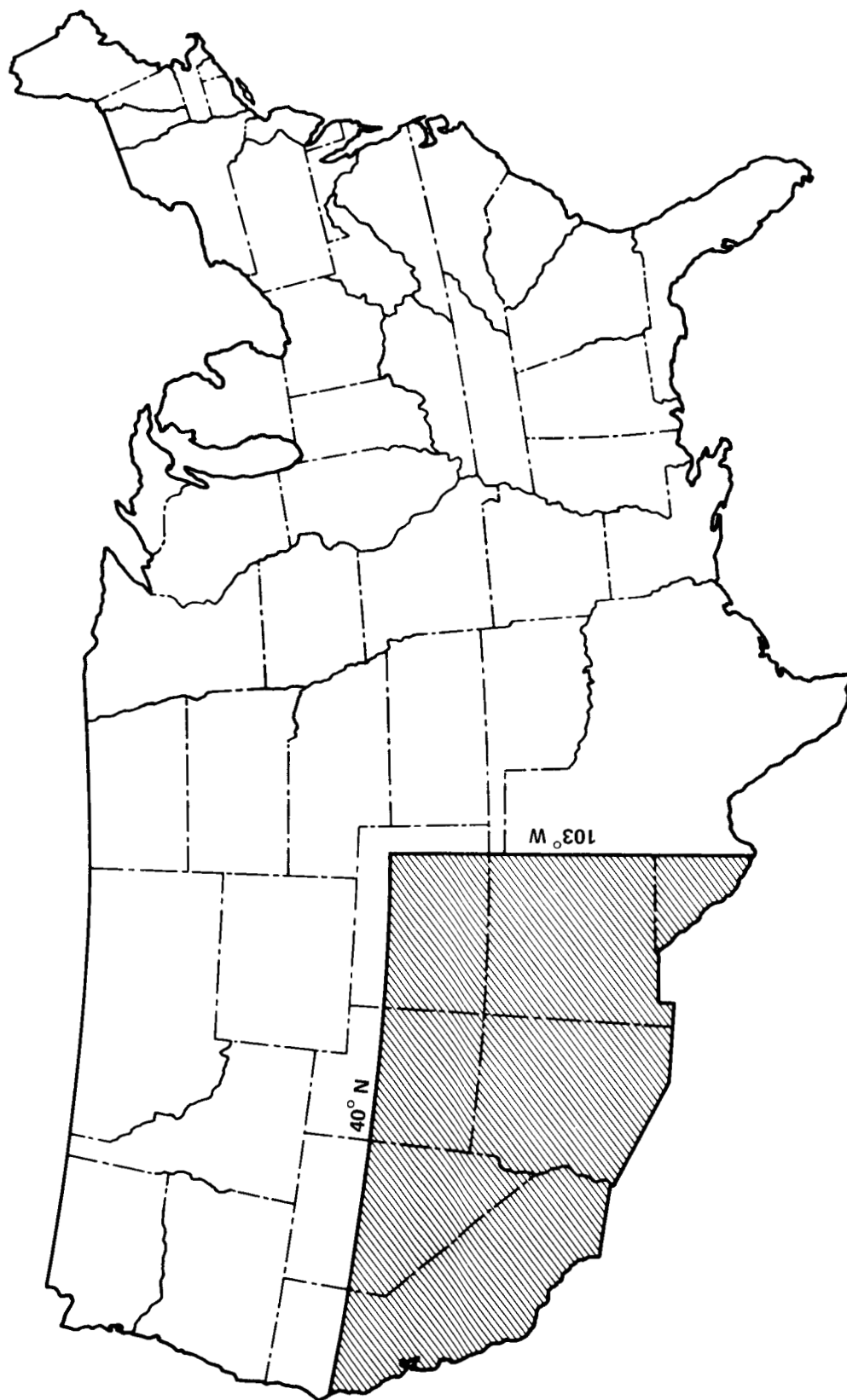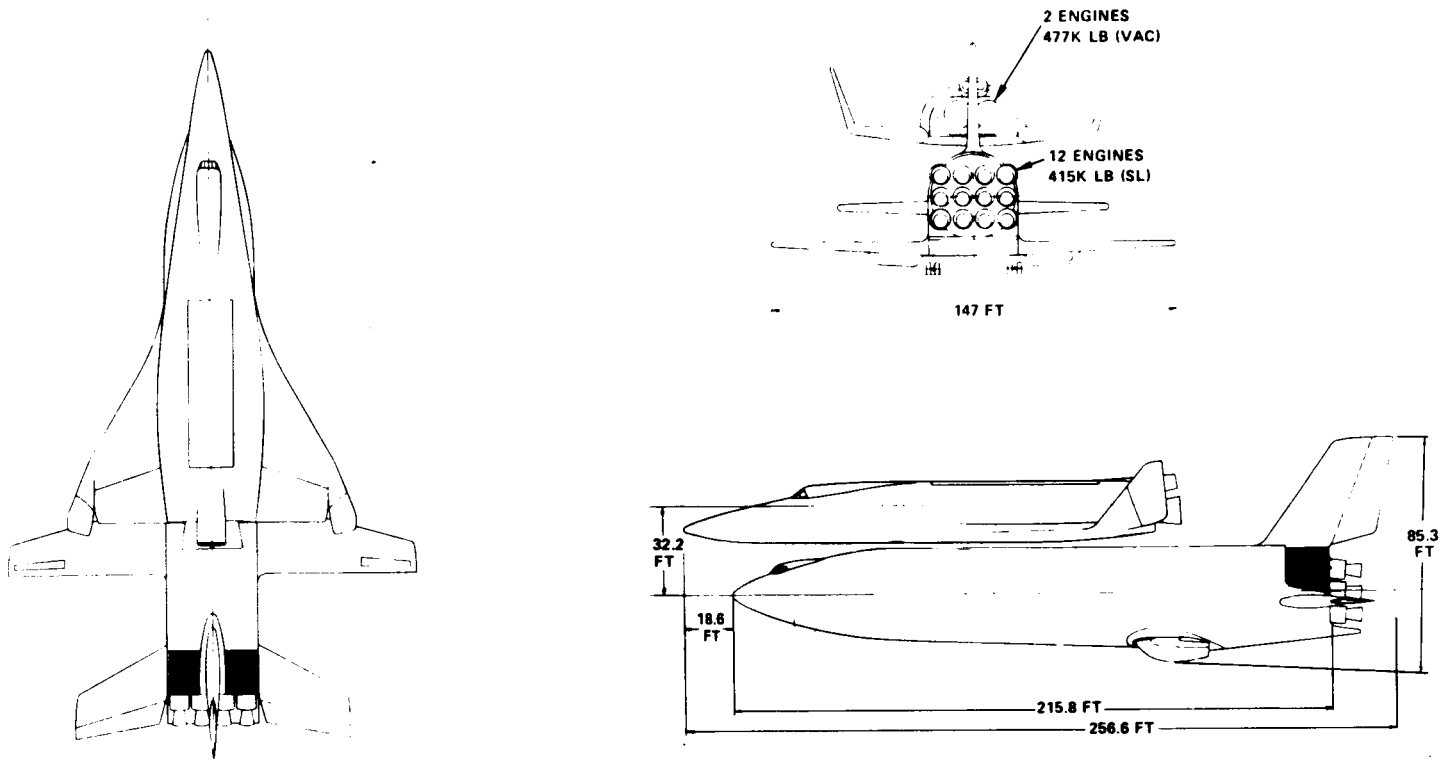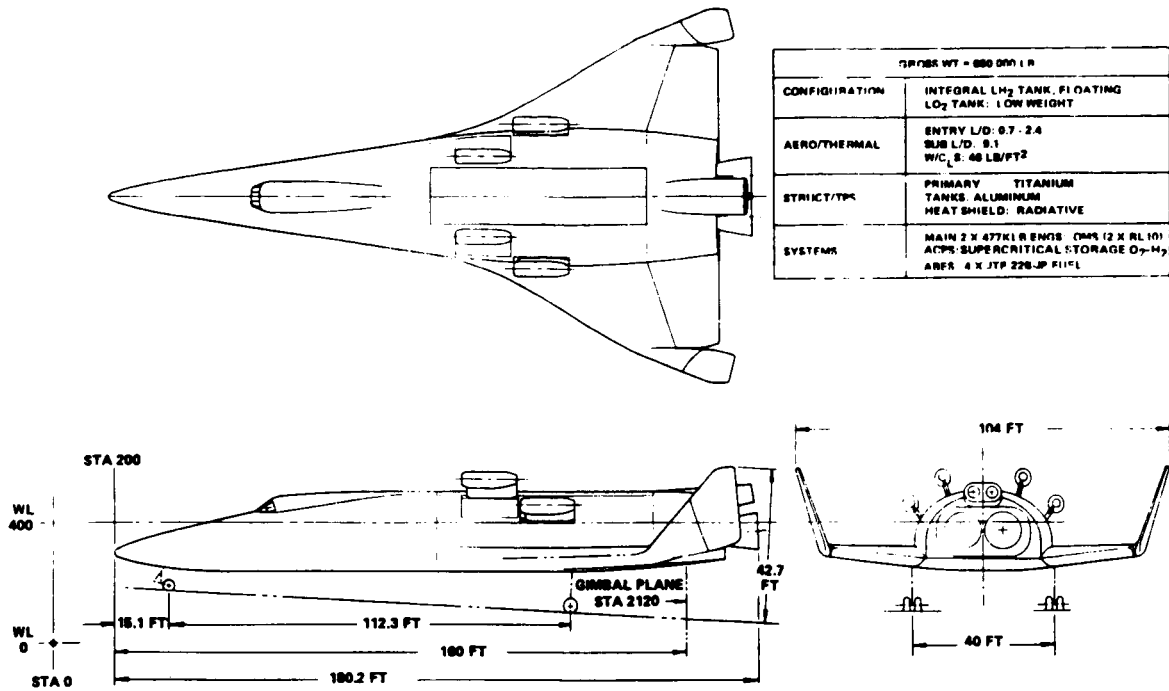[3] Assumes all months weighted equally.

103°W

40°N

FIGURE 1 - SOUTHWEST AREA CONSIDERED FOR COC

2 ENGINES
477K LB (VAC)

12 ENGINES
415K LB (SL)

147 FT

32.2 FT

18.6 FT

85.3 FT

215.8 FT

256.6 FT

ORBITER:		(POUNDS)
GROSS LIFT OFF WEIGHT	—	650,000
TOTAL LH$_2$ WEIGHT	—	62,000
TOTAL LO$_2$ WEIGHT	—	370,000
TOTAL JP 4 WEIGHT	—	3,600
LANDING WEIGHT (WITH P/L)	—	209,500
BOOSTER:		
GROSS LIFT OFF WEIGHT	—	3,330,000
TOTAL LH$_2$ WEIGHT	—	395,000
TOTAL LO$_2$ WEIGHT	—	2,370,000
TOTAL JP 4 WEIGHT	—	85,000
LANDING WEIGHT	—	480,000

FIGURE 2. MATED VEHICLE SYSTEM—DELTA WING
ORBITER & BOOSTER

ORBITER, DELTA WING

GROSS WT = 600,000 LB	
CONFIGURATION	INTEGRAL LH_2 TANK, FLOATING LO_2 TANK; LOW WEIGHT
AERO/THERMAL	ENTRY L/D: 0.7 - 2.4 SUB L/D: 9.1 W/C_L S: 46 LB/FT^2
STRUCT/TPS	PRIMARY TITANIUM TANKS: ALUMINUM HEAT SHIELD: RADIATIVE
SYSTEMS	MAIN 2 X 477KLB ENGS: OMS (2 X RL 10) ACPS:SUPERCRITICAL STORAGE O_2-H_2 ABES: 4 X JTF-22B JP FUEL

STA 200
WL 400
WL 0
STA 0
15.1 FT
112.3 FT
GIMBAL PLANE STA 2120
42.7 FT
180 FT
180.2 FT

104 FT
40 FT

ALTERNATE ORBITER, STRAIGHT WING

24.7 FT

GROSS WT = 675,000 LB	
CONFIGURATION	FLOATING TANKS
AERO/THERMAL	ENTRY L/D: 0.56 SUB L/D: 8.3 W/C_L S: FWD CG 54.3 LB/FT^2 AFT CG 47.0 LB/FT^2
STRUCT/TPS	PRIMARY TITANIUM TANKS: ALUMINUM HEAT SHIELD: RADIATIVE
SYSTEMS	MAIN 2-477 KLB ENGS; OMS: 2XRL-10 ACPS: SUPERCRITICAL. H_2-O_2 ABES: 4 X JTF-22B JP FUEL

STA 200
WL 400
WLO
STA 0
31 FT
79.8 FT
153.3 FT
GIMBAL PLANE STA 2040
66.8 FT
173.8 FT
34.7 FT
117.9 FT

FIGURE 3

ENTRY FLIGHT PROFILE FOR 200 N MI CROSS—RANGE

EVENT	V_R (FPS)	γ_R (DEG)	α (DEG)	φBANK (DEG)	t (SEC)	q̄ (PSF)	N (G's)	h
① ENTRY	25,134	-1.55	60	0	0	0	0	400,000
② PULL-UP (MAX TEMP)	24,350	-0.10	60	0→83	275	13	0.49	260,000
③ BEGIN EQUIL GLIDE	16,350	-0.48	60	20	650	30	1.16	222,000
④ MAX LOAD AT α = 60°	6,300	-3.3	60	20	900	45	1.69	161,000
⑤ 90° TURN	600	-54.3	60	20→0	1100	28	1.12	65,000
⑥ BEGIN TRANSITION	400	-53.0	60→10	0	1150	32	1.05	50,000
⑦ DIVE PULL-OUT	630	0	10	0	1180	130	1.96	38,000
⑧ LANDING TOUCH-DOWN	167 (KTS)	-0.43	12	0	2200	95	1.0	0

ENTRY FLIGHT PROFILE FOR 1500 N MI CROSS—RANGE

EVENT		h (FT)	V (FPS)	γ (DEG)	α (DEG)	φ(BANK) (DEG)	t (SEC)	q (PSF)	N(g's)
ENTRY	①	400,000	25,134	-1.55	53	0	0	0	0
PULLUP/PITCHDOWN	②	261,000	24,507	-0.12	53→30	0→68	271	12	0.46
BEGIN α MODULATION	③	218,000	17,712	-0.21	30	35	1120	42	0.70
END α MODULATION	④	143,000	8,721	-0.81	14	15	1920	174	0.92
MAX g	⑤	107,000	4,133	-1.75	14	15	2304	205	1.07
90° TURN	⑥	102,000	3,676	-1.88	14	15→0	2342	201	1.05
TURBOFAN IGNITION	⑦	46,000	655	-6.3	10	0	2992	126	1.0
LANDING	⑧	0	160 KTS	0	12	0	3968	87	1.0

DEORBIT TO 400,000 FT. (BOTH CASES)
β = 129 DEG. R = 7746 NM. t = 1977 SEC.

FIGURE 4. ENTRY FLIGHT PROFILES

FIGURE 5. FIRST REVOLUTION GROUND TRACK-LAUNCH TO NORTH FROM EDWARDS AFB

55° INCLINATION
50 x 100 N. MI. ORBIT

FIGURE 6. FIRST REVOLUTION GROUND TRACK-LAUNCH TO NORTH FROM HOLLOMAN AFB

FIGURE 7. FIRST REVOLUTION GROUND TRACK-LAUNCH TO NORTH FROM CAPE KENNEDY
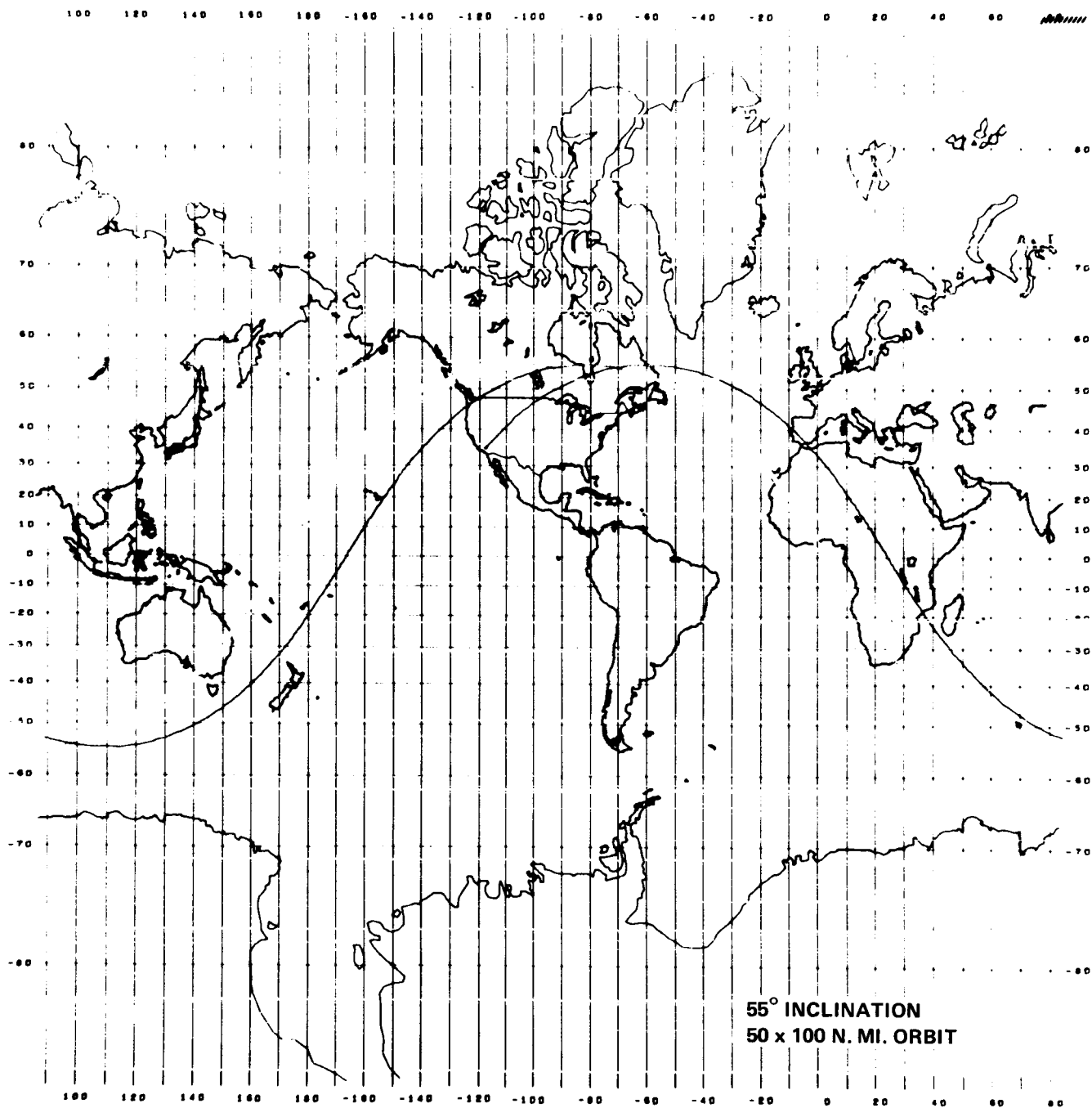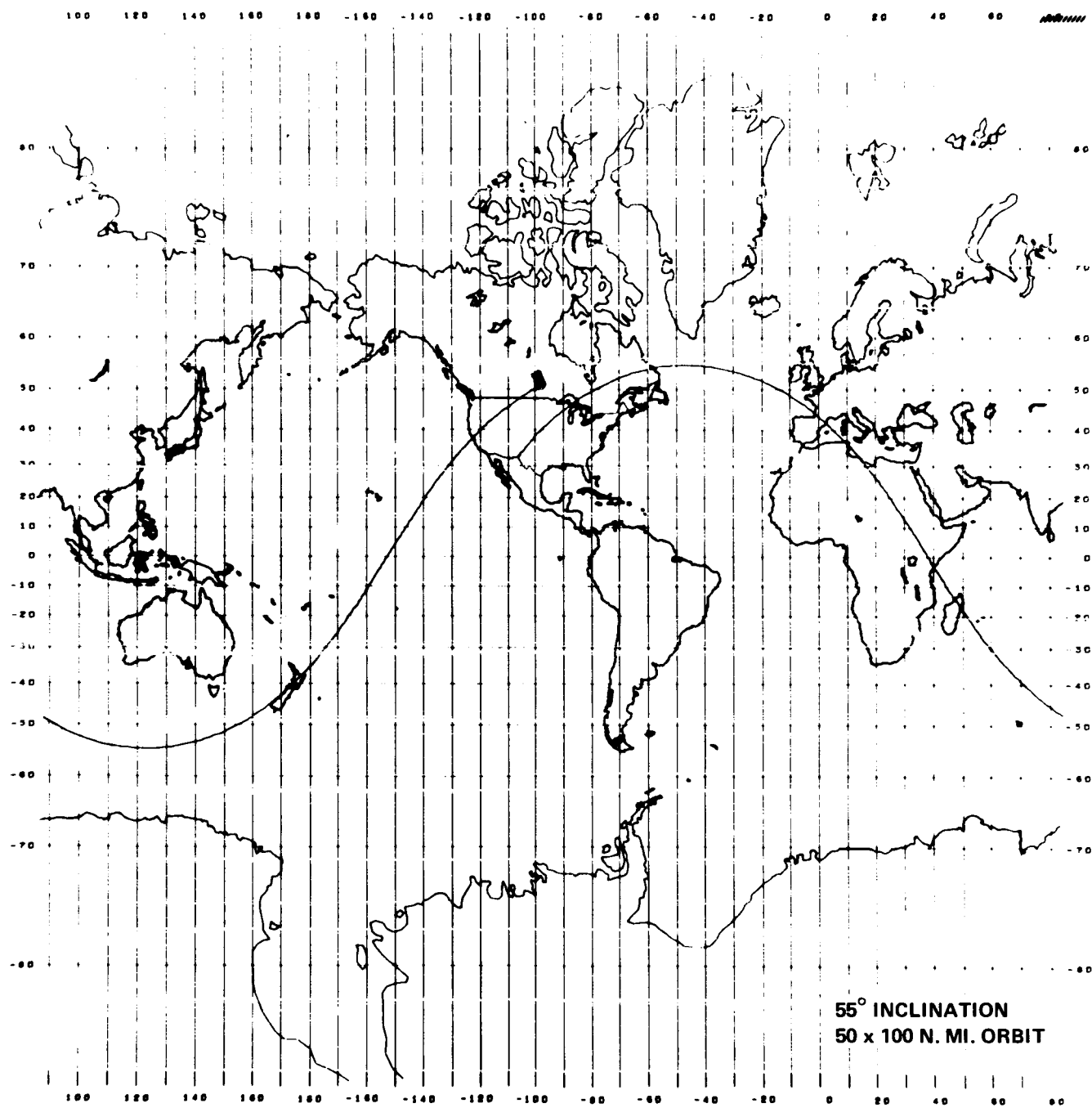
55° INCLINATION
50 x 100 N. MI. ORBIT

FIGURE 8. FIRST REVOLUTION GROUND TRACK-LAUNCH TO SOUTH FROM EDWARDS AFB

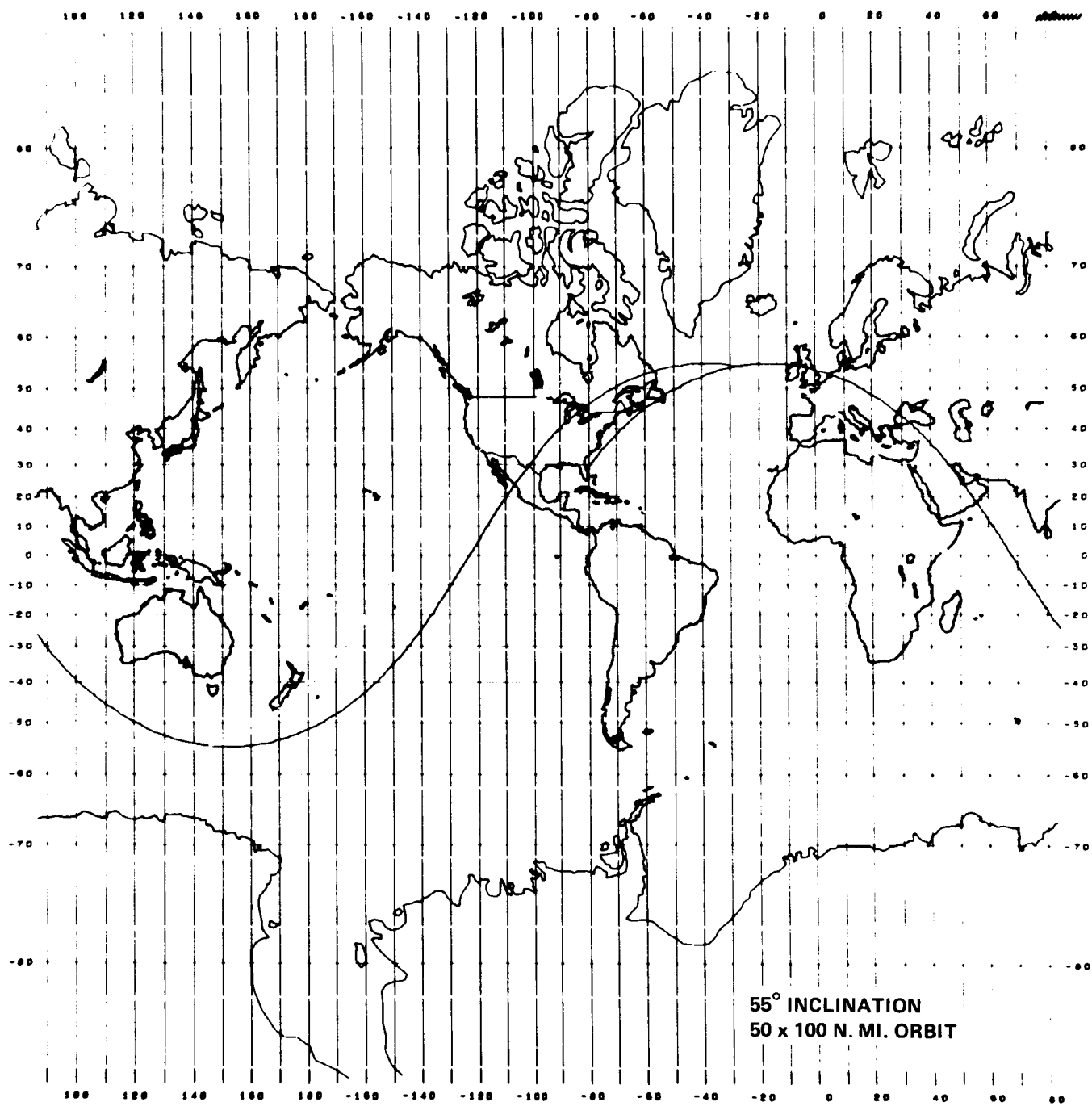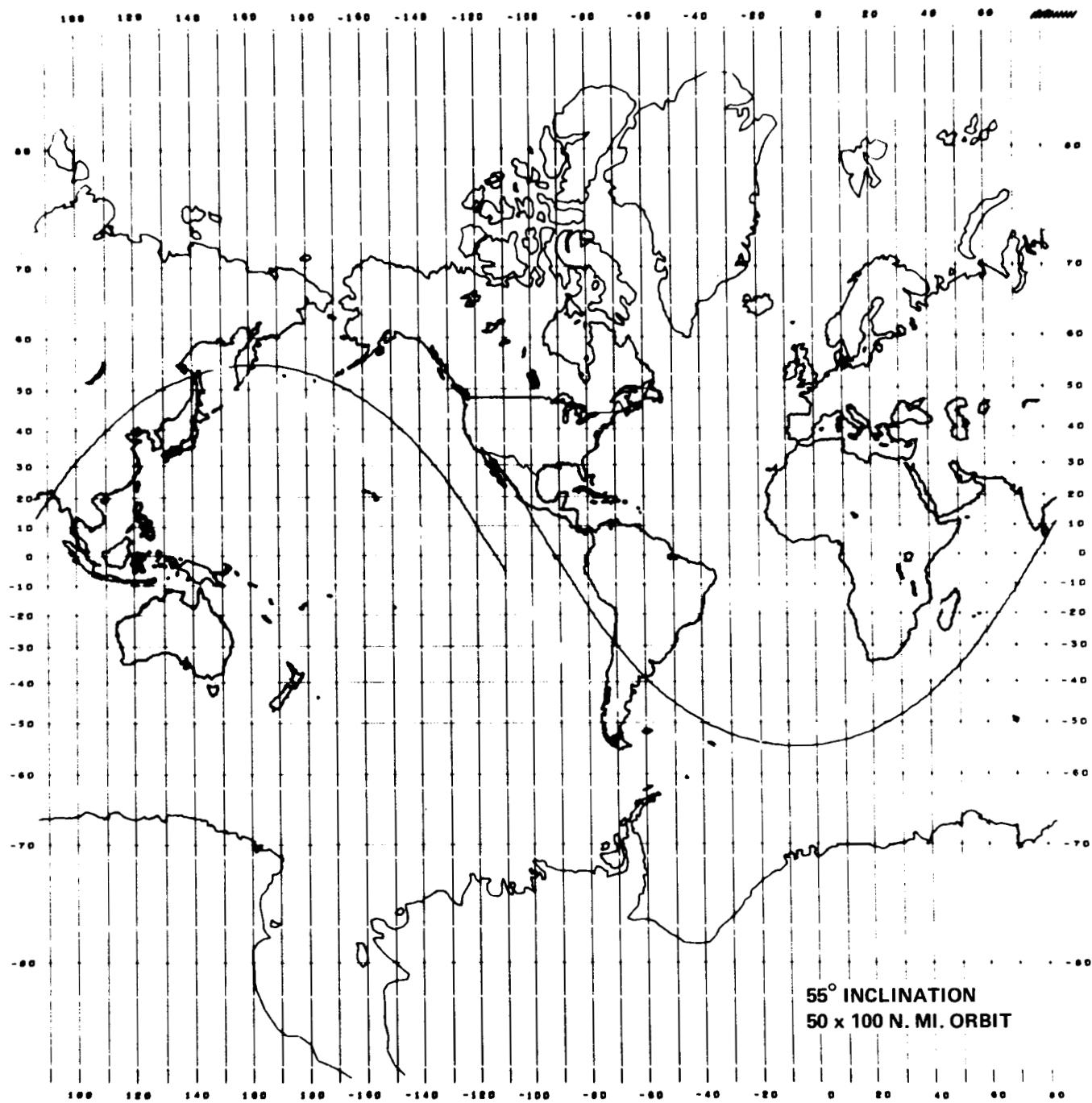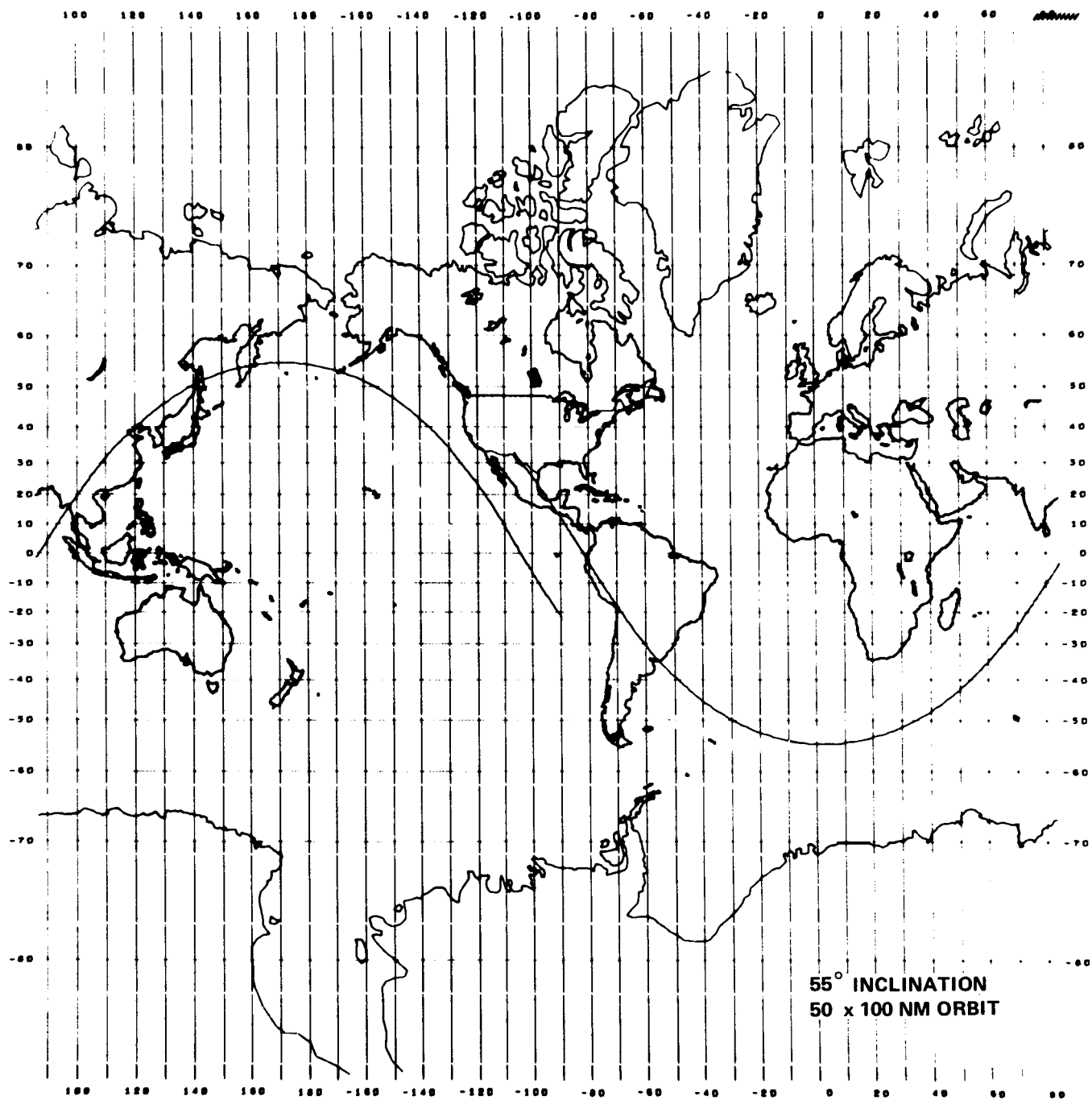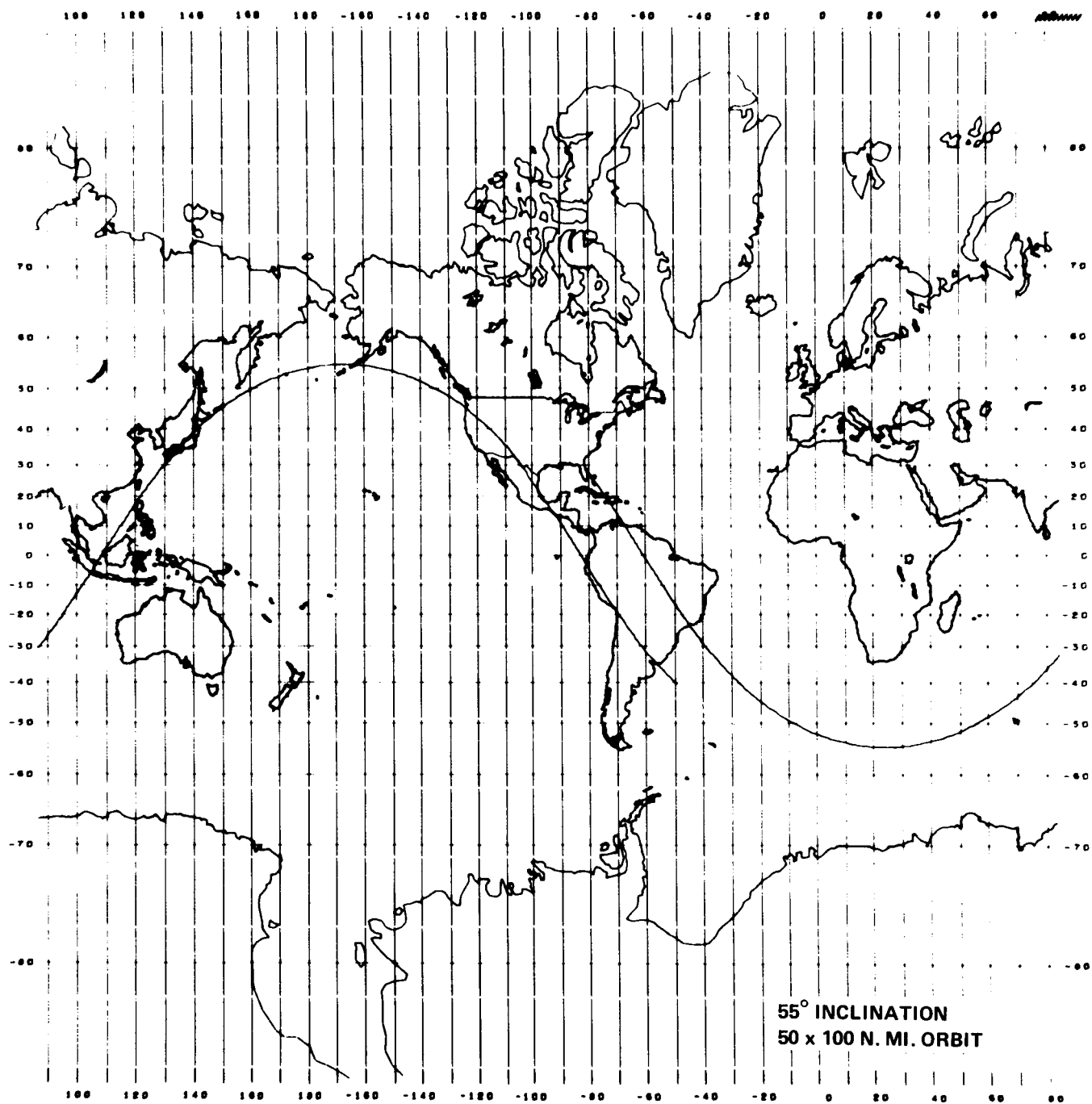**FIGURE 9. FIRST REVOLUTION GROUND TRACK-LAUNCH TO SOUTH FROM HOLLOMAN AFB**

FIGURE 10. FIRST REVOLUTION GROUND TRACK-LAUNCH TO SOUTH FROM CAPE KENNEDY

BELLCOMM, INC.

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APPFNDIX A

Communications & Navigational Aid Systems
for Recovery of Space Shuttles

A-I. Introduction

Various communications and navigational aids which could be located on-board the Orbiter and the Booster of the Space Shuttle and on the ground at the prime landing site to support recovery of both the Orbiter and the Booster are discussed. A compatible set of on-board (Section A-II) and ground-based (Section A-III) communications and navigational aid equipments to support recovery of the Space Shuttle elements is proposed for use in the Operational Support System study. The following requirements were used as a basis for this effort:

(a) The Orbiter shall have a two-man flight crew and shall be flyable by a single crewman under emergency conditions.

(b) The Booster shall be designed for manned operations (two-man flight crew) but shall be capable of operating in an unmanned mode.

(c) The Booster and Orbiter shall each have the capability to land horizontally on runways no longer than 10,000 feet.

(d) The Booster and Orbiter shall each be capable of ferry flights utilizing available civil and/or military ground facilities.

(e) The automatic landing approach capability provided in the Booster and in the Orbiter shall permit landings under Federal Aviation Agency (FAA) Category II visibility conditions (1200 feet Runway Visual Range, 100 feet decision height) at suitably instrumented landing sites.

(f) The Booster and the Orbiter shall each be capable of remote or pilot-controlled landings.

(g) Suitable FAA-ATC type ground facilities shall be used where possible to provide subsonic cruise navigation and automatic landing navigation for both the Booster and the Orbiter.

(h) Autopilot systems similar to those used in commercial aircraft shall be included in both the Booster and the Orbiter.

(i)   The Booster and the Orbiter shall be provided
      with the capability for voice communications with
      the FAA enroute, terminal area, and landing air
      traffic control (ATC) facilities.

(j)   The Booster and the Orbiter shall each be provided
      with at least the minimum number and type of navi-
      gational aids required by the FAA on aircraft flying
      under Instrument Flight Rules (IFR) in positively
      controlled airspace.

In addition to the capability for automatic landing
approach to permit landings under FAA Category II visibility
conditions at suitably instrumented landing sites, it is highly
desirable to provide the Orbiter and possibly the Booster with
the capability for automatic landings under FAA Category IIIC
visibility conditions (zero visibility) at suitably instrumented
landing sites.

A-II.   Avionics Systems On-Board the Space Shuttle

According to current FAA regulations, all friendly
aircraft flying between 24,000 feet (18,000 in some areas) and
100,000 feet in the airspace over the United States, its terri-
tories and its possessions and extending anywhere up to approxi-
mately 100 miles from its shorelines, all of which is controlled
by FAA-ATC, must follow Instrument Flight Rule (IFR) procedures.
Hence, all aircraft must have prior approval of FAA-ATC and
must be equipped with voice communications, navigational aid,
and radar transponder and beacon equipments compatible with the
ground-based FAA-ATC communications and air navigation equipments.
Flights over the ocean must adhere to the rules and procedures
established by the International Civil Aviation Organization (ICAO)
as applied by the country controlling the airspace and instrument
flight plans for aircraft must be filed before entering this
airspace. In general, the Air Traffic Control (ATC) systems of
the foreign countries belonging to ICAO are similar to those
used in the United States.

ICAO, an agency of the United Nations which formulates
standards and recommended practices for all civil aviation,
has standardized the characteristics of both the ground-based
and airborne portions of the following air navigation aids:

(a)   VHF Omnidirectional Range (VOR) which provides on-
      board bearing information to the pilot.

(b)   Distance Measuring Equipment (DME) which provides
      on-board range information to the pilot.

(c) Air Traffic Control Radar Beacon System (ATCRBS) which
     provides ground-based radar with a cooperative target
     and is capable of providing the ground controllers
     with aircraft identification and aircraft altitude.

(d) Instrument Low-Approach or Landing System (ILS) which
     provides on-board lateral guidance (localizer), ver-
     tical guidance (glide slope), and distance or check-
     point guidance (fan marker) to the pilot during final
     approach before landing.

Currently in the United States, all civil aircraft flying IFR
must at least carry a VHF communications transceiver covering
all of the ATC frequencies allocated for voice communications
(118 to 136 MHz which also corresponds to those frequencies
reserved for ATC voice communications in foreign countries), a
VOR receiver, an ATCRBS transponder, and the ILS receivers. It
is expected that use of DME by civil aircraft flying IFR in the
U. S. airspace will be required by FAA-ATC in the 1975-1980 time
frame. FAA believes that the existing enroute air navigation
system aids with some upgrading such as improved standards for
airborne equipment, improvements in VOR/DME, increased DME capacity,
etc., will be sufficient to serve the air traffic volume through
1980. Recommendations have been made, however, to replace the
conventional ILS with a scanning-beam microwave ILS for final
landing approach, landing, and terminal navigation and to provide
the capability to uplink commands via a data link to the aircraft.
FAA hopes that installation of a scanning-beam microwave ILS
alongside the conventional ILS at high-density traffic airports
can begin in 1975 with both systems to operate concurrently for
10 years or more.

     U. S. military aircraft which fly IFR carry the ATCRBS
transponder and the ILS receivers but are not equipped with a
VHF communications transceiver or a VOR receiver. Instead, these
aircraft carry a Tactical Air Navigation (TACAN) set and a
UHF voice communications transceiver which covers the 225 to
400 MHz frequency band which has been allocated for military use
in the U. S. The TACAN system through an on-board interrogator/
receiver provides the pilot with both distance and bearing infor-
mation. It should be noted that all ground-based TACAN beacons
provide full service to the DME interrogator carried by civil air-
craft and that ground-based DME beacons provide distance readings
to the TACAN sets on-board the military aircraft. In the U. S.,
TACAN beacons are co-located with VOR beacons at approximately
two-thirds of the VOR beacon station locations. Also in the U. S.,
ground communications facilities are scattered as required to
provide coverage of the entire controlled airspace and are re-
moted to the ground controller's location. There is a basic mini-
mum requirement of one VHF and one UHF voice channel per ATC sector

so that communication is possible between the ground controller
and both civil and military aircraft within his sector of re-
sponsibility.

The military has also set up Air Defense Identifica-
tion Zones (ADIZ's) for preserving the security of the U. S.
from potentially hostile aircraft. The military must be in-
formed of plans of any aircraft to enter an ADIZ before entrance
can be made or the aircraft will be intercepted. This could be
important during the reentry and recovery of the Orbiter and
liaison with the military as well as FAA-ATC will be required.

En-Route Communications and Navigational Aids

For a southwest U. S. location of the Centralized
Operations Center (COC), it is likely that the Orbiter will
fly over the ocean during aerodynamic braking and glide follow-
ing reentry into the Earth's atmosphere at 400,000 feet. For
over-ocean voice communications, FAA officials currently support
the international development of an L-Band satellite system for
voice communications and air surveillance including aircraft
position determination for worldwide implementation in the 1975-
1980 time frame. They also hope to proceed with early deployment
of an aeronautical satellite which could be used to relay VHF
communications.

Although communications between the Orbiter and the
ground controllers via an aeronautical telecommunications navi-
gation satellite would be desirable, it appears not to be manda-
tory. Since design of the guidance and navigation system of
the Orbiter will be based on on-board autonomy, the guidance
and navigation system of the Orbiter will not require position
updates during glide after any reentry RF communications black-
out has subsided. The only use for this position information
and voice communications (other than verification of safe reentry)
would then be for ATC purposes. Because of the relative infre-
quency of the Orbiter in the controlled airspace over an ocean
(approximately once per week in the assumed Space Shuttle schedule
model), it appears reasonable that a sufficiently large block of
airspace could be allocated by FAA-ATC for short-time use by the
Orbiter to accommodate uncertainties in Orbiter location caused
by deorbit and reentry dispersions until the Orbiter is picked
up by an Air Route Surveillance Radar (ARSR) of FAA-ATC. For
similar reasons, it appears that incorporation in the Booster
of the capability for communications with ground controllers via
an aeronautical telecommunications and navigation satellite
cannot be justified for Booster recovery purposes alone, although
it would be desirable.

From a safety standpoint, since liquid hydrogen is used as a propellant for the main engines of the Orbiter and Booster, and from a security viewpoint, since the Space Shuttle might be asked to fly some military missions, it appears to be desirable for the Orbiter and Booster to use U. S. military airport ground facilities as alternate landing sites for non-nominal flights when return to the primary landing site is not possible. Use of U. S. military controlled airport ground facilities appears to be especially desirable whenever possible in a contingency situation which requires the Orbiter to return to the Earth in the vicinity of a foreign country. Both civil and military airports could be used by both the Orbiter and the Booster during ferry flights.

Radio-inertial navigation is being planned for the Booster (and probably will be provided in the Orbiter) to provide the Booster with the capability to return to the vicinity of the designated landing site automatically in a manned or unmanned mode. Integration of the autopilot, autothrottle, radio navigational aids, and display systems will be required. Through use of a computer in addition to the existing TACAN or VOR/DME airborne equipment, automatic guidance of the Booster on any desired predetermined course will be possible within range of the appropriate VOR/DME, TACAN, or VORTAC ground installations. Approximate position information provided by the inertial equipment can be used by the computer to select the proper VOR, DME, and/or TACAN channel for use and the proper VOR or TACAN radial to follow. If the Booster will ever be operated in an unmanned mode, an updata link to the Booster will be required to provide the capability for remote control of the Booster from the ground or a chase plane in case of a failure in the primary radio-inertial navigation system.

In summary, it appears that both the Orbiter and the Booster will require the following types of navigational aid and communications equipments to be incorporated for use during the return to the vicinity of a designated landing site at the conclusion of their respective missions or during the enroute phase of a ferry flight. Equipment reliability and possible redundancy requirements have not been addressed.

    (a)   VHF transceiver (FAA-ATC),

    (b)   UHF transceiver (military),

    (c)   TACAN set,

    (d)   Precision-VOR receiver,

(e)   Fan Marker receiver, and

(f)   ATCRBS transponder.

The Precision-VOR receiver is compatible with the standard VOR beacon systems as well as the more accurate VOR beacon systems being installed by FAA-ATC in areas with high-density traffic; namely, Doppler-VOR and Precision-VOR beacon systems. See Table A-1 for a brief description of the operation of the equipments listed above.

An up-data link to the Booster would be needed to provide the data transfer capability for contingency remote flight control if the Booster were ever to fly unmanned. It appears desirable to use this up-data link for the transfer of any required data to the Booster during other phases of nominal Booster missions when remote flight control is not being exercised.

Terminal Approach and Landing Communications and Navigational Aids

The accuracy of the conventional ILS provided at most large airports is impaired by its susceptibility to reflection interference from nearby terrain, structures, large buildings, and other aircraft in the air or on the ground. In addition, continuous range information is not provided (although check points are provided by fan markers) and the ILS glide slope is not usable below approximately 100 feet because it assumes a hyperbolic shape below this altitude. Using special care to minimize siting problems, the conventional ILS at several airports have been qualified for use by suitably equipped aircraft in Category II landing approaches. The ILS localizer at selected airports could possibly be made usable for azimuthal guidance in Category III landings and rollouts, however, vertical guidance below 100 feet altitude would have to be provided by a non-ILS sensor such as a radar altimeter on-board the Orbiter and the Booster. The elevation angle of the glide slope beam of the conventional ILS is usually set between 2 and 3 degrees. It is possible, however, that the Orbiter and the Booster will use glide slope elevation angles considerably higher than this, probably of the order of 10 degrees. If the elevation angle of the glide slope beam of a conventional ILS were modified to accommodate the Orbiter and Booster using this higher than normal glide slope elevation angle, the ILS could not be used by conventional aircraft unless these aircraft were capable of also landing using this higher glide slope. Consequently, unless the elevation angle of the glide slope beam of the conventional ILS could be made variable, conventional ILS receivers would be of no value to an Orbiter or Booster using glide slope elevation angles different from 2 to 3 degrees when landing at existing

civil and military airports. Furthermore, if the higher glide
slope elevation angles are used, the Runway Visual Range (RVR)
and ceiling visibility requirements for safe landings using
instruments of varying accuracy may have to be modified for
application to the Orbiter and the Booster.

As indicated earlier, FAA hopes to begin deployment
in 1975 of a scanning-beam microwave ILS which will meet the
reliability and accuracy standards to permit landing of suitably
instrumented aircraft under FAA Category IIIA visibility con-
ditions (700 feet RVR, no decision height). The scanning-beam
feature provides the capability for covering wide sectors of
airspace which may be required for final approach maneuvering.
The use of microwave frequencies permits the use of narrow
beams which provides protection against interference from reflec-
tions. Hence, the scanning-beam microwave radar will be capable
of providing the required accuracy at the low vertical angles
required by an aircraft for flareout and landing. The rapidly
scanning azimuth and elevation beams will be angle coded so that
an airborne receiver can obtain the required azimuth and eleva-
tion information to permit a Category IIIA landing. In addition,
the airborne receiver will be able to derive range information
from the signals transmitted by the scanning-beam microwave ILS.
The Advanced Integrated Landing System (AILS) is an early
example of this type of system.

Accurate azimuth, elevation, range, altitude, and
crab information is required for Category IIIC landing and
accurate range and azimuth information is required for Category IIIC
rollout after touchdown. Improvement in the accuracy of ground-
based and airborne equipments of a scanning-beam microwave ILS
over that provided by the developmental AILS will be required
before a scanning-beam microwave ILS would allow landing of the
Orbiter or Booster under FAA Category IIIC visibility conditions.
If the accuracy of a scanning-beam microwave ILS cannot be im-
proved sufficiently, automatic landing of the Orbiter or Booster
could be achieved through use of a system similar to the existing
AN/SPN-42 Automatic Carrier Landing System currently being used
operationally by the U. S. Navy on selected aircraft carriers.
Use of this type of system would require the Orbiter and Booster
to be equipped with a radar transponder compatible with the
ground-based radar and an up-data link to allow transfer of
remote flight control commands from the ground. In any event,
integration of the autopilot, autothrottle, brakes, steering,
radio navigational aids, on-board sensors, and possibly the up-
data link will be required in the Orbiter and in the Booster
to provide the capability for automatic approach, landing and
rollout. On-board sensors would include a flare sensor (such as

a radar altimeter) to supply a flareout command at an appropriate wheel height and a sensor to detect the crab angle and to supply a decrab command at an appropriate wheel height. These on-board sensors would be required regardless of which of these landing systems were available at a landing site to be used.

In summary, since both the Orbiter and Booster (possibly unmanned) should be able to land at civil and/or military airports other than the prime recovery airport, it appears that both the Orbiter and the Booster will require the following types of navigational aids and communications equipments to be incorporated for use during the final landing approach, landing and rollout at any designated landing site. Equipment reliability and possible redundancy requirements have not been addressed.

(a)   VHF transceiver,

(b)   UHF transceiver,

(c)   Conventional ILS receivers (localizer, glide path, and fan marker receivers),

(d)   Scanning-beam microwave ILS receiver(s),

(e)   Radar altimeter, and

(f)   ATCRBS transponder.

See Table A-2 for a brief description of the operation of these equipments.

An up-data link to the Booster will be required for remote control of landing approach, landing, and rollout in a contingency situation if the Booster were ever to fly unmanned. This up-data link would be the same link that was discussed in the previous section on en-route communications and navigational aids. In the event that the accuracy provided by the scanning-beam microwave ILS is not sufficient to permit landing of the Orbiter and Booster under FAA Category IIIC visibility conditions and this capability becomes a mandatory requirement for the Orbiter and Booster, a radar transponder and an up-data link would be required on both the Orbiter and the Booster to permit remote control as discussed earlier. It is assumed that the normal up-data links to the Orbiter and Booster, respectively, would be shared for this purpose.

A-III.   Ground-Based Avionics Systems

Since the launch pad, the primary landing site, and
the Space Shuttle service and refurbishment facility will be
located in the same general area, the 10,000 foot minimum run-
way providing the primary landing and recovery site for both
the Orbiter and the Booster will most likely be used quite ex-
tensively as a landing field for aircraft transporting freight
and personnel. Consequently, the communications and navigational
aid equipments provided at this primary landing site should
include those required for the safe final approach, landing,
and rollout of civil and military aircraft as well as the Orbiter
and Booster. It appears that the following types of communica-
tions and navigational aid equipments will be required at or
near this site. Equipment reliability and possible redundancy
requirements have not been addressed.

(a)   VHF/UHF air/ground voice communications equipment,

(b)   TACAN station,

(c)   Precision-VOR beacon located at the TACAN station,

(d)   Airport Surveillance Radar (ASR),

(e)   Secondary Surveillance Radar (SSR), the ground-
based portion of the ATCRBS,

(f)   Conventional Category II ILS,

(g)   Scanning-beam microwave ILS,

(h)   Fan Markers as required for check point indication
(in addition to those provided with ILS),

(i)   Precision-Approach Radar (PAR) or Ground-Controlled
Approach Radar (GCA),

(j)   Medium Intensity Approach Light System with Runway
Alignment Indicator Lights (MALS/RAIL) suitable for
Category II landings,

(k)   Airport Surface Detection Equipment (ASDE), and

(l)   Transmissometer(s).

It should be noted that the information provided by
the PAR (or GCA) could be provided by the scanning-beam micro-
wave ILS if the final system design of this system incorporates

the capabilities provided in AILS, a developmental scanning-beam microwave system. In that event, the PAR (or GCA) could prob- ably be eliminated.

Cost estimates for equipment procurement and installa- tion are listed in Table A-3. It is assumed that any commands sent to the Booster for control during approach and landing, if the capability for a remotely controlled landing is incorporated in the Booster, would be accomplished via the normal Booster up- data link and no additional recovery-peculiar equipments would be required at the prime landing site for this purpose.

It is envisioned that the TACAN station including the Precision-VOR equipment would be located to provide an outer fix from which the Orbiter and Booster could be automatically vectored to the final landing approach window of the ILS and PAR for auto- matic or manual landing. A second TACAN station with co-located Precision-VOR equipment would be required to provide another outer fix if the capability to oand the Orbiter and/or Booster in either one of the two directions on the runway is required. Co- located TACAN and Precision-VOR beacons are required to service aircraft equipped with either TACAN or VOR receivers but not both.

The ASR is required to establish the bearing and range of all aircraft (cooperative or non-cooperative) within a 30 mile radius in order to locate any aircraft which could possibly inter- fere with the safe approach of the Orbiter or Booster. The ASR would also be used to provide ground controller(s) with aircraft azimuth and range information required to control aircraft movement in the terminal area including sequencing and positioning aircraft for final approach and landing.

The SSR is the ground portion of the ACTRBS and is moun- ted on top of and slaved to the ASR antenna, although it is other- wise independent of the ASR. The SSR is required to establish bearing, range, and altitude (altitude determined from beacon code responses) of cooperative targets within a 200 mile radius in order to provide ground controller(s) with sufficient infor- mation to permit remote control of an unmanned Booster in a con- tingency situation or provide advisory information to a manned Orbiter or Booster. The SSR data would also be used by ground controller(s) to locate cooperative aircraft targets which could possibly interfere with the safe approach of the Orbiter or Booster and to control aircraft flying IFR in the terminal area.

The PAR or Ground-Controlled Approach (GCA) radar covers a relatively narrow sector in both azimuth and elevation and is used to determine whether an aircraft is following the

prescribed angle of descent and is aligned with the runway. The
PAR is required in order to provide a ground controller with the
necessary accurate azimuth, elevation, and range information
to permit remote control landing of the Booster (if this capa-
bility is provided in the Booster) in the event of a failure
in the automatic landing system of an unmanned Booster; and to
provide advisory voice information to pilots of aircraft, a
manned Orbiter, or a manned Booster. It is assumed that the
PAR can be implemented so that landings from either direction
can be accommodated, however, a second PAR would not be provided
in any event because of its position in the backup hierarchy.

It is envisioned that the scanning-beam microwave
ILS will be the primary source of azimuth, glide slope, and range
data to the Orbiter and Booster for automatic (or manual) land-
ing approach, landing, and rollout. Two scanning-beam microwave
ILS's will be required if the option to land on the runway from
either direction is to be provided. The conventional ILS is
required for aircraft not equipped with a scanning-beam micro-
wave ILS receiver and possibly for contingency situations such
as failure of Orbiter or Booster on-board scanning-beam micro-
wave ILS receiver(s) providing the Orbiter and Booster can use
low glide slope elevation angles for landing. Only one conven-
tional ILS would be required because of its position in the
backup hierarchy and it would be located to cover the more likely
landing direction.

In the event that an all-weather landing capability
becomes a mandatory requirement for both the Orbiter and the
Booster and sufficient accuracy cannot be provided by the ground-
based and on-board elements of a scanning-beam microwave ILS sys-
tem to permit landing under FAA Category IIIC visibility condi-
tions, a system similar to the existing AN/SPN-42 Automatic
Carrier Landing System could be used to provide this all-weather
landing capability. In this type of system, a precision tracking
radar would automatically acquire and track a transponder carried
by the Orbiter and Booster and would provide this data to a digital
computer. This measured flight path of the Orbiter or Booster
would be compared in the computer with its desired flight path.
Appropriate commands for remote control of the Orbiter or Booster
to correct its flight path would be generated by the digital com-
puter for transmission via an up-data link to the Orbiter or
Booster. It is assumed that any commands sent to the Orbiter or
Booster for control to achieve an all-weather landing would be
transmitted via the normal Orbiter and Booster up-data links,
respectively, and no additional up-data transmission facilities
would be required at the primary landing site for this purpose.
If an AN/SPN-42 Automatic Carrier Landing System which does not
include an up-data transmission capability was purchased as a
package, the cost would be approximately 2 million dollars.

The ASDE is required for monitoring airport surface traffic in darkness and during periods of poor visibility. The ASDE is required to provide the ground controller with sufficient information to remotely control the Booster if unmanned during rollout after landing in a contingency situation in order to ensure that the Booster will complete its rollout within the lateral and longitudinal boundaries of the runway. It is likely that the aircraft traffic at this airport will be sufficiently small so that the movement of aircraft and vehicles on the surface could be readily controlled by visual observation from a tower, if one is provided, during periods of good visibility. However, visual observation is not mandatory with information from the ASDE available.

The transmissometer(s) is required for measurement of RVR.

As has been suggested by the discussions above, a control room and/or control tower will be required for control of aircraft using the runway and the terminal airspace for providing advisory and/or control information to the Orbiter and Booster in contingency situations during recovery, for remotely controlling the landing approach, landing, and rollout of the Orbiter and the Booster if required, and for maintaining liaison with FAA-ATC and the military. Liaison with the military will be required not only to advise them of future entry of the orbiter into ADIZ's but also to obtain ephemeris data on the Space Station, the orbiting Space Shuttle (Orbiter), and other satellites which might be chosen for investigation during an Orbiter mission. It is estimated that it would cost $350,000 to establish an aircraft control room or tower over and above the building cost. It is estimated that a total of 25 controllers would be required for continuous manning of the aircraft control room or tower and that a total of 25 maintenance people would be required to maintain the recovery communications and navigational aid equipments as well as the corresponding control room equipments in operational order.

Table A-1

Space Shuttle En-Route Communications and Navigational Aids

Function/System	Frequency (MHz)	On-Board Action Required	On-Board Readout
Voice Communications			
. VHF Transceiver	118-136	Select Proper Channel	
. UHF Transceiver	225-400	Select Proper Channel	
Navigational Aids			
. TACAN (includes DME)			
.. Airborne Receiver and Interrogator	1025-1150	. Select Proper one of 126 Channels	. Left-Right Indication from Radial
.. Ground-Based Beacon and Transponder	962-1024 1151-1213	. Select Proper one of 360 Radials	. Digital Distance to Ground-Based Transponder
. VOR	108-118	. Select Proper one of 80 Channels	. Left-Right Indication from Radial
		. Select Proper one of 360 Radials	
. Fan Marker	75	.None	. Discrete Indication when within fan marker antenna beam.
. ATCRBS			
.. Airborne Transponder	1090	. Select Proper Code Reply	. None
.. Ground-Based Interrogator	1030		
Up-Data Link (Booster Only)			

Table A-2

Space Shuttle Terminal Approach and Landing Communications and Navigational Aids

Function/System	Frequency (MHz)	On-Board Action Required	On-Board Readout
Voice Communications			
• VHF Transceiver	118-132	Select Proper Channel	
• UHF Transceiver	225-400	Select Proper Channel	
Navigational Aids			
• Conventional ILS			
•• Localizer Receiver	108-112	• Select Proper one of 20 Channels	• Left-Right indication from proper flight path
•• Glide Path Receiver	329-335	• 20 Channels Paired with Localizer Channels	• Up-down indication from proper flight path
•• Fan Marker Receiver	75	• None	• Discrete indication when within fan marker antenna beam
• ATCRBS			• None
•• Airborne Transponder	1090	Select Proper Code Reply	
•• Ground-Based Interrogator	1030		
• Scanning-Beam Microwave ILS (e.g. AILS)	K_u-Band		• Left-Right indication from proper flight path • Up-down indication from proper flight path • Range
• Radar Altimeter			• Altitude with respect to local terrain
Up-Data Link (Booster Only)			

Table A-3

Cost Estimate for Hardware Procurement and Installation
Ground-Based Recovery Communications and Navigational Aid Equipments

Equipment Type	Estimated Cost per unit (Dollars)
VHF/UHF Air/Ground Communications Equipment	75,000
TACAN Station	250,000
Precision-VOR Beacon (co-located with TACAN)	125,000
Fan Marker	10,000
ASR/SSR	1,500,000
Conventional Category II ILS	200,000
Scanning-Beam Microwave ILS	500,000
PAR	750,000
MALS/RAIL	375,000
ASDE	250,000

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APPENDIX REFERENCES

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